

# Neoconstructivism: The New Science of Cognitive Development

## Scott Johnson

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### Shape, Action, Symbolic Play, and Words: Overlapping Loops of Cause and Consequence in Developmental Process

Linda B. Smith (Contributor Webpage), Alfredo F. Pereira

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## Abstract and Keywords

Human beings are remarkably inventive, possessing the ability to solve problems and to create novel things. This chapter focuses on an early form of inventiveness that has long intrigued developmentalists—what is sometimes called symbolic play, but more narrowly, is also known as “object substitution in play.” The specific phenomenon consists of young children using some object, not for what it is, but as a “stand in” for something else in play—a banana as a phone, a box as a doll bed, a shoe as a toy car. The chapter considers how and why these object substitutions may be linked to language.

Keywords: object substitution, language, children, play behaviour, learning

Human beings are remarkably inventive, possessing the ability to solve problems and to create novel things. This chapter is about one early form of inventiveness that has long intrigued developmentalists—what is sometimes called symbolic play, but more narrowly, is also known as “object substitution in play.” The specific phenomenon consists of young children using some object not for what it is but as a “stand in” for something else in play—a banana as a phone, a box as a doll bed, a shoe as a toy car. Piaget (1962) considered object-substitution in play—the using of a banana as phone, for example—as “symbolic” because the substituted object could be interpreted as “standing for” the real thing. This view that object-substitution is a form of symbolizing (whatever precisely that means) has been disputed (Namy, 2002; Perner, 1991). Regardless of different opinions

on this issue, object substitution in play remains a signal of developmental achievement, emerging at the same time (18 to 24 months) as children's spoken vocabulary also expands. Perhaps most critically, object substitution in play is strongly linked to individual children's language development (see McCune, 1995; McCune-Nicolich, 1981; Shore, O'Connell, & Bates, 1984; Veneziano, 1981), with the lack of this behavior being a strong predictor of significant subsequent language delay (e.g., McCune-Nicolich, 1981; Weismer, 2007). This chapter is about how and why these object substitutions may be linked to language learning through developmental changes in visual object recognition.

At a broader level, this chapter is about the fundamentally constructive nature of developmental process itself: how development creates new forms of behaviors and abilities from interaction of multiple processes, engaged in different assemblies in overlapping tasks; how every developmental cause is itself a consequence of developmental process; how development is made of weird loops of causes and consequences with far-reaching and unexpected developmental dependencies.

A summary of the developmental story we will narrate is provided by Figure 6.1: Learning object names increases children's attention to shape, which in turn speeds up object name learning. Learning object names also changes how children perceive object shape, which facilitates learning and generalizing object names and of actions. Acting on objects, in turn, refines and tunes—making even more abstract—the representation of object shape. Along the way, we will suggest and provide evidence for the idea that the abstract representation of object shape is the critical link between object name learning and object substitutions in play.

## LOOP 1: LEARNING TO ATTEND TO OBJECT SHAPE

Common object categories, categories such as chair, cup, spoon, house, and dog are (by adult **(p. 110)**)

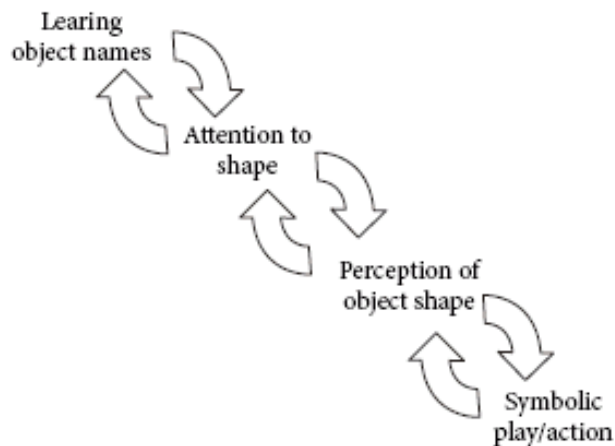


Figure 6.1 **Loops of causes and consequences in the development of visual object recognition.**

judgment) well organized by shape (Biederman, 1987; Rosch, Mervis, Gray, Johnson, & Boyes-Braem, 1976; Samuelson & Smith, 1999). More critically, in the vocabulary of typically developing 2-year-olds, over 70% of the nouns are for objects similar in shape (Samuelson & Smith, 1999). Accordingly, a large literature has been concerned with children’s attention to three-dimensional object shape in the context of early word learning. Landau, Smith, and Jones (1988) reported one key result: They showed 2- and 3-year-old children a novel wooden object of a particular shape and named it with a novel count noun, “This is a dax.” The children were then presented with test objects that matched the exemplar in shape, size, or texture and were asked about each of those objects “Is this a dax?” Children generalized the name to test objects that were the same in shape as the exemplar but not to test objects that were different in shape. The degree of children’s selective attention to shape was considerable: for example, they extended the name “dax” to same-shaped test objects that were 100 times the size of the original. This “shape bias” in novel noun generalization tasks has been demonstrated in many different studies and by different experimenters using a variety of both specially constructed and real objects (e.g., Gathercole & Min, 1997; Imai, Gentner, & Uchida, 1994; Keil, 1994; Soja, 1992) and is evident in children learning a variety of languages (Colunga & Smith, 2005; Gathercole & Min, 1997; Yoshida & Smith, 2003). This substantial area of research has generated a large number of well-replicated results important to the first loop.

First, attention to shape increases as children learn object names. Children initially (12- to 18-month-olds, see Gershkoff-Stowe & Smith, 2004; Rakison

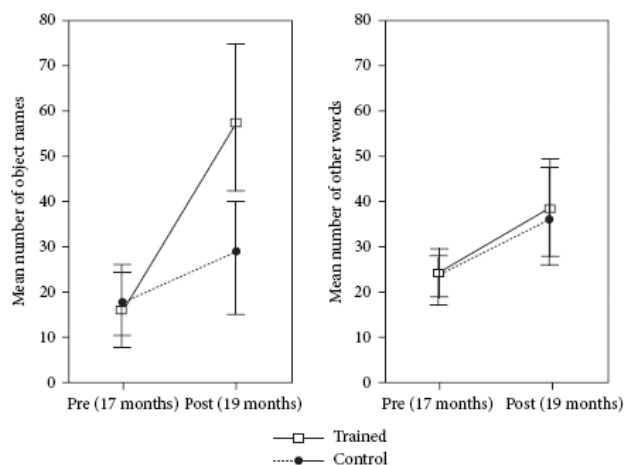
& Butterworth, 1998a, 1998) do not systematically attend to object shape in naming and categorization tasks, but increasingly do so in the period between 18 and 30 months. Moreover, longitudinal studies show that in individual children, the emergence of the shape bias is temporally linked to a measurable spurt in the growth of object name vocabulary (Gershkoff-Stowe & Smith, 2004). Attention to shape also predicts developmental delays. Late talkers—children delayed in their early noun acquisitions—show systematic deficits in attention to object shape in naming tasks (Jones, 2003; Jones & Smith, 2005).

Second, attention to shape is causally related to object name learning. Teaching children to attend to shape facilitates novel noun acquisitions and accelerates the rate of real-world vocabulary development (Smith, Jones, Landau, Gershkoff-Stowe & Samuelson, 2002; see also, Samuelson, 2002). This study was a 9-week longitudinal study. The children were 17 months of age at the start—too young to show a shape bias in novel noun generalization tasks and also on the early side of the increasing rate of new object names that begins around 18 to 22 months for most children. The children in the “Experimental” condition came to the laboratory once a week for 7 weeks. During that time, they played with 4 pairs of objects. The objects in each pair matched in shape but differed markedly in all other properties—color, texture, material, and size. The objects in each pair were named by the same novel name (e.g., “dax, riff, zup, toma”) and during each weekly play session, the experimenter named each of these training objects by its designated name at least 20 times.

On week 8, children’s ability to generalize these trained names was tested. If children learned that two particularly shaped objects were “daxes,” would they judge a novel object—new size, new color, new material but the same (p. 111) shape—to also be “a dax?” The answer is yes; the children learned the category. On week 9, children were tested in a novel noun generalization task, with all new objects and all new names. If shown a new never-before-seen thing and told its name, would these children know how to generalize the name to new instances by shape? Again, the answer is yes. The children learned not just about particular categories and the importance of shape, but also that shape in general matters for naming objects. A variety of control conditions were run in these series of training studies, including grouping without naming, playing with objects with neither grouping or naming, or learning names for groups organized by texture or color. None of the children in these training groups generalized novel names for novel things on week 9 by shape.

The most dramatic result from these studies is the finding that training children to attend to shape in this laboratory task increased their rate of new object name acquisitions outside of the laboratory. Figure 6.2 shows the number of object names in children's productive vocabulary (as measured by the MCDI, Fenson et al., 1994) at the start and end of the experiment. There was a marked increase in new noun learning for children in the Experimental but not the Control conditions, and training influenced the rate with which children in the Experimental condition added new objects names to their vocabulary but not the rate with which they added other words. Learning names for things in shape-based categories teaches children to attend to shape when generalizing names for things, and doing so accelerates the learning of new object names, lexical categories that are in general well-organized by shape.

These training experiments may be microgenetic and targeted versions of what happens in the everyday development. In the real world, young children more slowly learn names for many different things at the same time. Although these categories are not as well organized by the shape as the training categories, many are categories of things that are mostly similar in shape. As children learn these categories, attention to shape in the context of naming things may increase, and, as a consequence, children may learn object names more rapidly, which should further tune attention to object



**Figure 6.2 Object names and other words in children's productive vocabulary at the start and end of training in the Smith et al. ( 2002 ) study.**

(p. 112 ) shape. Every word learned sets the stage for and constrains future learning. The shape bias in early noun learning is in this way both a cause and a consequence of learning object names.

## LOOP 2: BUILDING ABSTRACT REPRESENTATIONS OF OBJECT SHAPE

There is one critical unexplained aspect of Loop 1. In order for a shape bias to work to help children learn names for everyday object categories, children must be able to recognize sameness in shape across different instances of a category. This is trivial in artificial noun-learning tasks since all objects are relatively simple and “same-shaped” (objects are the *exact* same shape). But this is not trivial in the real world. In order for children to learn, for example, that chairs are “chair-shaped” and to use that knowledge to recognize a new chair, they must be able to abstract the common shape from a whole array of chairs that have been experienced, each with its own unique and detailed shape. Real world instances of common noun categories, though judged by adults to be the “same shape” (e.g., Samuelson & Smith, 1999) are not exactly the same shape, but only similar in shape at some appropriate level of abstraction. This then is the critical next question: What is the proper description of shape for common object categories? When and how do children discover that description? Before answering this question, we step back to consider what is known about adult shape representations and visual object recognition.

The first key fact about human visual object recognition is that it is impressive: it is fast, seemingly automatic, robust under degraded viewing conditions, and capable of recognizing novel instances of a very large number of common categories (Biederman & Gerhardstein, 1993; Cooper, Biederman, & Hummel, 1992; Fize, Fabre-Thorpe, Richard, Doyon, & Thorpe, 2005; Pegna, Khateb, Michel, & Landis, 2004). The second key fact is that object recognition is not a single skill but a consortium of abilities. For example, in their everyday lives, people routinely recognize the dog whose nose is sticking out from the blanket, the highly unique modernistic chair, and the cup on the table as a particular and favorite cup. Although competing theories of object recognition (Biederman, 1987; Edelman, 1999; Ullman, 2000) often pit different kinds of hypothesized processes and representations against each other, it is likely that human object recognition is dependent on a multitude of partially distinct and partially overlapping processes (Hayward, 2003; Hummel, 2000; Marr, 1982; Peissig & Tarr, 2007; Peterson, 1999). That is, no single mechanism is likely to explain the full

range of contexts in which people recognize objects as individuals and as instances of categories.

Theories of object recognition that concentrate on how people rapidly recognize instances of novel categories (and approaches to machine vision that attempt to build devices that can recognize novel instances of categories) often propose processes of shape recognition that depend on abstract, sparse representations of the global shapes of things. There are two general classes of such theories. According to “view-based” theories, people store representations of specific views of experienced instances and use prototypes—a kind of average simplified shape that captures the global structure—to recognize new category instance (Edelman, 1995; Edelman & Duvdevani-Bar, 1997; Edelman & Intrator, 1997). In Edelman’s (1995) account, category learning plays the critical role in creating prototypes of the holistic shape of category members. Novel instances are subsequently categorized by their overall similarity to these representations.

“Object-based” theories such as Biederman’s (1987) recognition-by-components (RBC) account present another idea about what constitutes “sameness in shape.” This theory proposes that objects are perceptually parsed, represented, and stored as configurations of geometric volumes (“geons”). Within this account, object shape is defined by 2 to 4 geometric volumes in the proper spatial arrangement, an idea supported by the fact that adults need only 2 to 4 major parts to recognize instances of common categories (Biederman, 1987; Hummel & Biederman, 1992) as illustrated at the bottom of Figure 6.3. This account thus posits sparse and impoverished representations that, through their high level of abstraction, can gather all

(p. 113 )



**Figure 6.3 Pictures of some of the three-dimensional objects, richly detailed and shape caricatures, used in Smith ( 2003 ).**

variety of highly different things into a “same shape” category. Both classes of theories fit aspects of the adult data, which include strong view dependencies in object recognition and also knowledge of part structure and relations. Accordingly, there is a growing consensus that both kinds of theories may capture important but different processes in mature object recognition (Hayward, 2003; Peissig & Tarr, 2007; Peterson, 1999; Stankiewicz, 2003; Tarr & Vuong, 2002). For this chapter, the important point is that both approaches posit that sparse and abstract representations of object shape support the recognition of instances of common object categories. The question we want to answer is when and how children develop these representations. Despite the importance of object recognition to many domains of cognitive development, there was, until recently, extraordinarily little developmental research in this area (see Kellman, 2001).

The first study (Smith, 2003) asked whether young children (18 to 24 months) could recognize instances of common object categories from sparse representations of the geometric structure as can adults (e.g., Biederman, 1987). The experiment specifically contrasted richly detailed typical examples with “shape caricatures” as shown in Figure 6.3. The task was name comprehension (“get the camera”) and the 18- to 24-month participants were grouped into developmental level by the number of object names in their productive vocabulary. The main results were that children with smaller and larger vocabularies (below 100 object names versus more than 100 object names) recognized the richly detailed instances equally well. However, children with smaller noun vocabularies performed at chance levels when presented with the shape caricatures, whereas the children with high noun vocabularies recognized the shape caricatures as well as they did the richly detailed and typical instances.

These results have been replicated in two further studies (Son, Smith, & Goldstone, 2008; Pereira & Smith, 2009). Further, a study of older late talkers (children whose productive vocabulary is below the 20th percentile for (p. 114 ) their age) found a deficit in the recognition of shape caricatures but not richly detailed typical instances (Jones & Smith, 2005). Altogether, these results suggest a potentially significant change in how young children represent and compare object shape that is developmentally linked to the



learning of objects names. In particular, sparse representations of object shape appear to emerge between 18 and 24 months.

One other line of research suggests that these developmental changes may also involve a shift in the kind of stimulus information used to categorize and recognize objects. In particular, a number of studies suggest that children younger than 20 months attend to the individual parts or local details of objects rather than overall shape (Rakison & Butterworth, 1998). In a series of programmatic studies, Rakison and colleagues (Rakison & Butterworth, 1998b, Rakison & Cohen, 1999, Rakison and Cicchino, 2008) showed that 14- and 22-month old children based category decisions on highly salient parts (such as legs and wheels) and not on overall shape. For example, when children were presented with cows whose legs had been replaced by wheels, they classified the cows with vehicles rather than animals; likewise they categorized a vehicle as an animal when it had cow legs. Similarly, Colunga (2003) showed that 18-month-olds tended to only look at a small part of any pictured object, using clusters of local features such as the face when recognizing animals, or the grill and headlights when recognizing vehicles.

These results raise the possibility that very young children—perhaps before they develop more sparse representations of object structure—recognize objects via what Cerella (1986) called “particulate perception,” concentrating on local components unintegrated into the whole. Such “part”-based object recognition is also suggestive of an approach to object recognition that has emerged in the machine vision literature: in particular, Ullman has developed a procedure through which objects are successfully recognized via stored representations of category specific fragments (Ullman & Bart, 2004; Ullman, Vidal-Naquet, & Sali, 2002). If adults possess multiple distinct processes of object recognition that are used in different contexts or for different kinds of tasks, perhaps these processes each have their own developmental trajectories with more “fragments” or “feature” processes developing earlier and sparse representations of global geometric structure emerging as a consequence of learning many shape-based object categories (see also the chapter in this volume by Johnson, for a similar developmental trajectory in young infants’ perceptual completion).

Pereira and Smith (2009) provide support for this idea in a direct comparison of young children’s ability to recognize objects given local featural details versus global geometric structure. The stimulus sets that they used resulted from a 2 × 2 design: the presence and absence of global information about geometric structure (which they labeled by +*Shape Caricature* and

-*Shape Caricature*) and localized and fine detailed information predictive of the category (which they labeled by *+Local Details* and *-Local Details*). Examples of the four stimulus conditions are in Figure 6.4. The *+Shape Caricatures*, structured as in the Smith (2003) experiment were made from 1 to 4 geometric components in the proper spatial relations. The *-Shape Caricatures* were alterations of the *+Shape caricatures*: the shapes of at least two component volumes were altered and if possible the spatial arrangements of two volumes relative to each other were rearranged. The presence of detailed local information was achieved by painting surface details on these volumes that were predictive of the target category, for example, the face of a dog, wheels, and so forth.

Figure 6.5 shows the main result; the darker bars indicate performance when local details were present (*+Local Details*) and the solid bars indicate performance given the *+Shape caricatures*, that is, when the appropriate though sparse global shape structure was present. The children in the lowest vocabulary group show their highest level of performance (the darker bars) when the stimuli present local details, and for these stimuli, the presence or absence of appropriate shape structure does not matter. The children in the most advanced vocabulary group perform best given the appropriate sparse

(p. 115 )

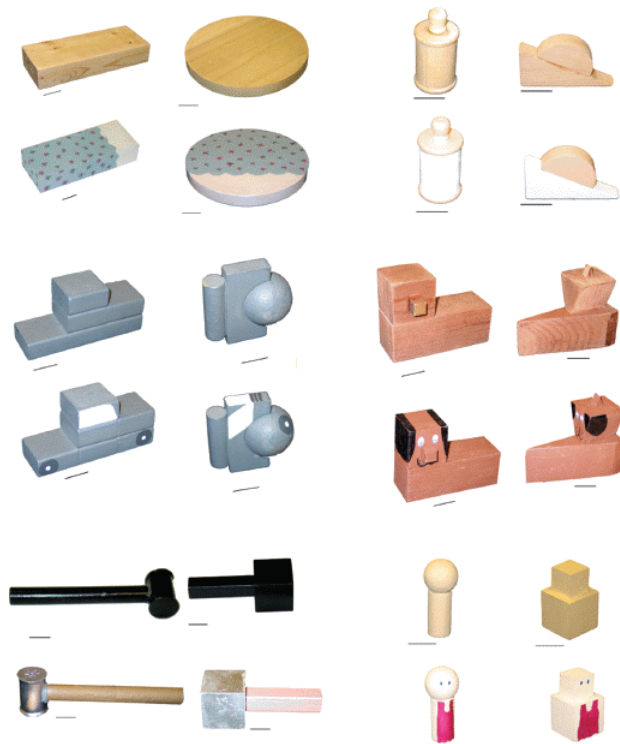


Figure 6.4 **Photos of the stimuli used in Pereira and Smith's ( 2009 ) experiment 2. Each set of four pictures contains clockwise from the upper left: (-Local Details, +Shape Caricature), (-Local Details, -Shape Caricature), (+Local Details, -Shape Caricature), (+Local Details, +Shape Caricature). The black line close to each object is one inch in length.**

representations of global shape. In brief, there is increasing recognition of the shape caricatures with increasing vocabulary size and a greater dependence on local features earlier in their vocabulary development. These results add to the growing number of findings suggesting significant changes in visual object recognition in the second year of life (Rakison & Lupyan, 2008; Smith, 2003; Son, Smith, & Goldstone, 2008).

The very idea that object recognition may change substantially during this developmental period is not commonly considered in studies of categorization and concepts in infancy and early childhood. This is so even though we know that there is at least one domain in which recognition undergoes significant changes as a function of development and experience. Specifically, face recognition is characterized (p. 116 )

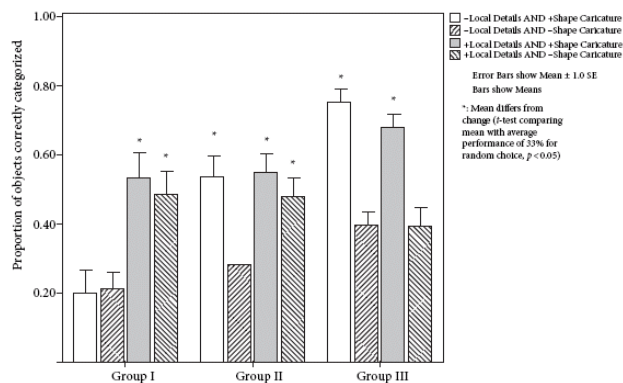


Figure 6.5 **Mean proportion of number of objects correctly categorized (out of 6 trials) across the three groups of vocabulary level for the Local Details × Shape Caricature interaction (Pereira & Smith, 2009 ). Between-subjects conditions -Local Details and +Local Details are shown in white and black bars, respectively. Within-subjects conditions +Shape Caricature and -Shape Caricature are shown in solid and patterned bars, respectively.**

by strong early sensitivities in infancy yet also shows a slow and protracted course of development with adult-like expertise not achieved until adolescence (e.g., Mondloch, Le Grand, & Maurer, 2002). In this context, the

idea of significant changes in object recognition and a possibly protracted course of development seem less surprising (as also suggested by Abecassis, Sera, Yonas, & Schwade, 2001).

It seems likely that the visual system develops the kinds of representations that support the task that needs to be done (Biederman & Kalocsai, 1997; Nelson, 2001). The task of object recognition for *many* different categories with *many* different potential instances in each category may demand a more abstract and geometric description of object shape—one in which, for example, a chair is a horizontal surface (to sit on) and a vertical surface (to support one's back). The period in which children learn the names for many different categories of things could be a driving force behind these developments. And certainly, more abstract representations of object shape may foster more rapid category learning and generalization (see especially, Son, Smith, & Goldstone, 2007).

At the very least, there is growing evidence for significant changes in visual object recognition during the developmental period in which children's object name learning is rapidly expanding. Multiple kinds of information may be used to recognize objects and it appears that very young children, at the start of a period of rapid category learning, mostly rely on detailed local information to recognize instances of common categories but not more abstract information about geometric structure. Children who are only slightly more advanced, however, do recognize common objects from such shape caricatures. This period of rapid developmental change seems crucial to understanding the nature of human object recognition and may also provide a crucial missing link in our understanding of the developmental trajectory in early object name learning, a trajectory of vocabulary growth that begins slow but **(p. 117 )**



**Figure 6.6 Sample stimulus set from Smith and Pereira ( 2008 ) for the symbolic play task.**

progresses to quite rapid learning characterized by the fast-mapping of object names to categories of things alike in shape.

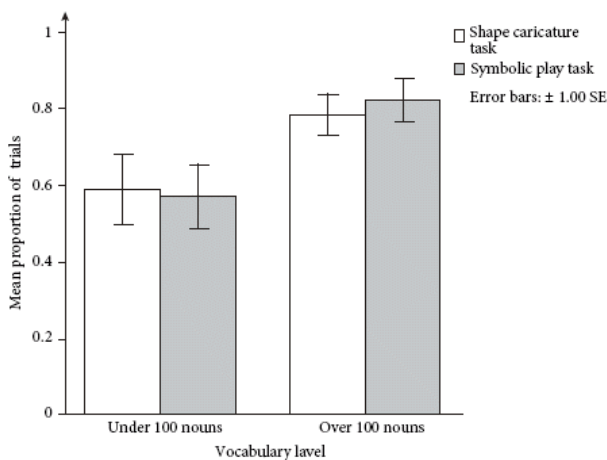
### Unexpected Connections—Symbolic Play

These changes in visual object recognition raise a new hypothesis about the developmental origins of object substitutions in play. Although these inventive actions seem likely to involve many interacting processes (including wanting to engage in thematic play), they may also depend critically on abstract descriptions of object shape. Using a banana as a phone, a shoe as a car, a stick as a bottle, and a pot as a hat all suggest sensitivity to high-level structural properties of shape. Accordingly, in a recently completed study, we examined whether children's recognition of shape caricatures might predict the likelihood of object substitutions in play (Smith & Pereira, 2008). The participants were children 17 to 22 months of age. There were three dependent measures: (1) the number of nouns in the children's productive vocabulary (by MCDI parent report, see Fenson et al., 1993), (2) children's recognition of common categories from shape caricatures (given that they could recognize richly detailed instances of the same thing), and (3) performance in a symbolic play task.

To encourage children to engage in symbolic play, they were given a set of toys organized around a theme but with one key object missing. A sample set is shown in Figure 6.6. For this set, the child was given a doll, a blanket, and a pillow—three objects suggesting a “going to bed” theme—but no bed. Instead the fourth object was block. The question was whether the child would engage in thematic play, using the block as a bed. There were four such sets, the bed theme, an eating theme (doll, plate, spoon, pompoms to be potentially used as food), a car theme (road, bridge, stoplight, wooden shoe to be potentially used as car), and a house theme (house, table, chair, and stick to be potentially used as a person). Because children might inadvertently use the object in a way consistent with its targeted role, we required that children do two successive acts involving the target object in thematic play (e.g., laid the doll on the block then immediately put the blanket on the doll) to score it as an instance of symbolic play.

Figure 6.7 shows the performances of children with fewer and greater than 100 object names in their vocabulary: the proportion of shape caricatures they recognized (given they recognized the richly detailed instances) and the proportion of trials on which they engaged in symbolic play (as defined above). Children with fewer than 100 object names in their productive

vocabulary were much less likely to use the target objects in thematic play and also much less likely to recognize the shape caricatures for (p. 118 )



**Figure 6.7 Mean proportion of trials on which children with fewer and with more than 100 object names in productive vocabulary recognized the shape caricatures in the caricature recognition task and used the target object for the missing object in the symbolic play task (Smith & Pereira, 2008 ).**

common nouns. In contrast, children with over 100 object names in their productive vocabulary both used the target object for the missing object and also readily recognized the shape caricatures for common categories. Across the 36 children who participated in this study, there was a strong correlation between recognition of shape caricatures and symbolic play ( $r = .66$ ,  $p < .001$ ). Further a control study, which replaced the target object with richly detailed instances (e.g., replaced the block with a toy bed, the stick with a person), did not yield vocabulary-related differences in symbolic play nor a reliable correlation with shape caricature recognition. Finally, although vocabulary and age are correlated, size of the object name vocabulary is a better predictor of both symbolic play and shape caricature recognition than is age (see also, Pereira & Smith, 2009).

Although many abilities seem likely to be important to the development of thematic play and children’s inventive object substitutions in that play, these results suggest that these object substitutions may be, at least in part, linked to language through developmental changes in visual object recognition, which are influenced by learning names for things.

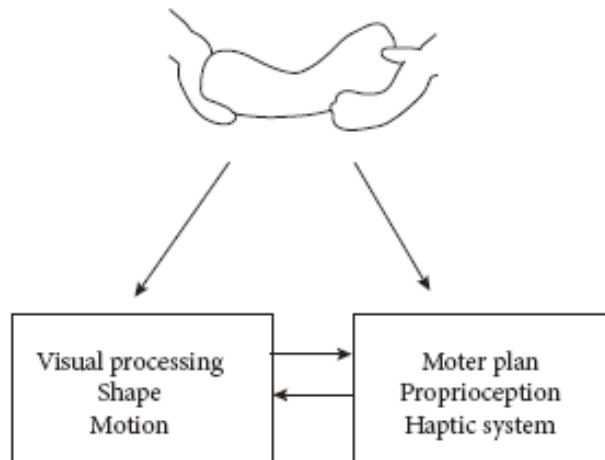
## LOOP 3: ACTION AND SHAPE PERCEPTION

The link between object substitution in play and the recognition of three-dimensional caricatures of the geometric structure of common objects suggests that an abstract and sparse description of object structure invites the generalization of actions and potentially classes of actions. This makes sense as there is a strong causal link between the shape of things, how they are held, how they feel while being held, and the actions those objects afford.

Contemporary research in cognitive neuroscience also indicates a coupling between brain regions involved in visually recognizing objects and in producing action that may be particularly relevant to an understanding of the developmental relationship between the abstraction of sparse descriptions of object structure and action. In particular, perceptual-motor interactions have been shown in behavioral paradigms and in recordings of brain activation (Christou & (p. 119) Bulthoff, 1999; Craighero et al., 1996; Freyd, 1983; Harman, Humphrey, & Goodale, 1999; James, Humphrey, & Goodale, 2001; James et al., 2002; Tong et al., 1995; Wexler & von Boxtel, 2005; A. Wohlschläger & A. Wohlschläger, 1998). Specifically, there appear to be automatic links among visual systems used for object perception and recognition, and motor systems used to act on objects (Arbib, 1981; Chao & Martin, 2000; Grezes & Decety, 2002; James et al., 2006; Longcamp, Boucard, Gilhodes, & Vely, 2005; Paillard, 1991; Viviani & Stucchi, 1992) such that, upon visual perception of an object, motor areas are automatically activated. These studies have demonstrated that activation in motor cortices emerges upon visual presentation of manipulable objects such as tools (Chao & Martin, 2000) and kitchen utensils (Gerlach et al., 2000; Grezes & Decety, 2002; Grezes et al., 2003; Mecklinger, Gruenewald, Besson, Magnie, & Cramon, 2002); and manually created objects such as letters (James & Gauthier, 2006; Longcamp et al., 2005). That is, visual presentations of objects with which we have had extensive motor interactions appear to automatically activate the motor areas responsible for those actions.

There are several open questions about these links, including why and how they are constructed, and whether they play a role in visual recognition (James & Gauthier, 2006; Mecklinger et al., 2002; Wexler & van Boxtel, 2005). One possibility is that such links are neural correlates of mere associations, so that although the motor regions are activated in response to visual stimuli, perhaps as preparation for action, they play no role in the visual recognition of the objects. A second possibility is that these motor activations feed back on and actually influence and help select activations in visual regions. More radically, a third possibility is that a developmental

history of the dynamic coupling of visual and motor activations constitutes the stored representation of the object, with the history of activations in visual regions influencing stored representations in motor regions, and with the history of activations in motor regions influencing stored representations in visual regions.



**Figure 6.8 A schematic representation of the inter-relating of multiple simultaneous representations across modalities.**

Figure 6.8 provides a schematic representation of this possibility—of what Edelman (1987) calls *re-entry*, the explicit interrelating of multiple simultaneous representations across modalities. For example, when a child is given a toy to hold and look at, both the visual and motor systems are simultaneously engaged. Together, they yield a constellation of sensations and movements associated with various actions on the toy and their consequences. Importantly, these multimodal experiences are time-locked and correlated. Changes in the way the hand feels when it moves the toy are time-locked with the changes the infant sees as the toy is moved. The time-locked correlations potentially create a powerful learning mechanism, as illustrated in the figure, which shows five related mappings. One map is between the physical properties of the toy and the neuronal activity in the visual system. Another map is between the physical properties of the toy and neuronal activity in the motor planning, proprioceptive, and haptic systems. A third map is between the motor systems and actions on the object. The fourth and fifth maps are what Edelman calls the re-entrant maps: activity in the visual system is mapped to the motor (and haptic and proprioceptive) systems, and activity in the motor system is mapped to the visual system.



Thus independent mappings of the stimulus—the sight of it and the action on it—provide qualitatively different takes on the world.

**(p. 120 )** By being correlated in real time, these different takes can potentially educate each other. At the same time as the visual system is activated by time-varying changes in visual information about shape and collinear movement of points on the toy, the motor and proprioceptive system is activated by action and felt movements. At every step in real time, the activities in these heterogeneous processes are mapped to each other, potentially enabling the coupled systems through their own activity to discover higher-order regularities that transcend the individual systems considered alone. Again, developmental relations may be bidirectional—changes in the perception of object shape may foster the generalizations of actions, and action, in turn, may promote attention to or the representation of relevant geometric properties of shape.

As a first step in considering how action may educate a sparse structural description shape—the kind of category encompassing description that enables one to recognize the sameness in shape across all varieties of shape—we have concentrated on two structural properties that are related to each other, commonly considered important across a wide variety of different theories of human and machine visual object recognition and potentially informed by action: (1) planar and nonplanar views and (2) the major axes of an object. We consider each of these in turn, presenting background on why they are likely structural properties for seeking a relation between action and object recognition and also new evidence suggesting marked developmental change during the period between 18 to 24 months.

## Preferred Views

There is ample evidence that not all viewpoints of objects are equal in terms of the ease with which an object is recognized from that viewpoint. Two views—off-axis versus on-axis views—have generated considerable interest in the adult object recognition literature. These two perspectives, illustrated in Figure 6.9 are often called the “3/4” and “planar” (front on and side on) views. These are the terms we will use here. With familiar objects, adults can recognize an object faster from a single image if that image is a 3/4 or off-axis view than if it is a planar view (Blanz, Tarr, & Bulthoff, 1999; Humphrey & Jolicouer, 1993; Lawson & Humphreys, 1998; Newell & Findlay, 1997; Palmer, Rosch, & Chase, 1981). In addition, when asked to pick the “best”

view of an object, adults will usually pick a 3/4 view (Blanz et al., 1999; Palmer et al., 1981). Critically, these results are specific to the



Figure 6.9 **A planar and nonplanar view of an object.**

(p. 121 ) recognition of pictures of well-known category instances. When adults are asked to pick the “best” view of a novel object, the planar views are picked as often as the 3/4 views (Blanz et al., 1999), perhaps because these views are less likely to occlude relevant object features that cannot be inferred for novel things. Similarly, when adults dynamically explore novel objects prior to visual recognition tasks, they actually prefer planar over 3/4 views. That is, during active exploration, adults spend a significantly greater amount of time looking at views of objects where axes are foreshortened (front) or elongated (side) (Harman et al., 1999; James et al., 2001, 2002; Perrett & Harries, 1988; Perrett et al., 1992). The suggestion from the above work is that the preferred view of an object depends upon whether the task is one of recognition (retrieval of information) or exploration (encoding of information), on whether the object in question is highly familiar or novel, and on whether it is a static, two-dimensional representation versus an actively perceived three-dimensional thing.

In a series of studies particularly relevant to our developmental work, James and colleagues asked the adult subjects to view, for later tests of recognition, computer rendered, virtual 3-D objects on a computer monitor by rotating them using a trackball device (Harman et al., 1999; James et al., 2001). Subjects rotated the objects in any dimension ( $x$ ,  $y$ , and  $z$ ) for a total of 20 s. The subjects spent most of their viewing time on the planar views (see also James et al., 2002; Perrett & Harries, 1988; Perrett, Harries, & Looker, 1992). In a separate experiment, James et al. (2001) also showed that dynamically viewing mostly planar views facilitated subsequent recognition when compared with the dynamic viewing of mostly 3/4 views. Thus, not only do adults prefer to study planar views of novel objects, but also when these

views are controlled experimentally, dwelling on and around the planar views promotes the formation of more robust memories of object shape.

When and how do these preferences emerge developmentally? We have new results (Pereira, James, Smith, & Jones, 2007) that suggest that this preference emerges between 18 and 24 months, the very same period in which children learn many object names, in which the shape bias emerges, in which children begin to recognize objects from sparse representations of geometric structure, and in which they first show shape-based object substitutions in thematic play. One cannot ask 18- to 24-month-old children to manipulate computer-rendered images with a trackball (the method used by James et al.). What we did instead was that we asked children to manually and visually explore objects while wearing a head-camera, a methodology for tapping the first-person view developed by Yoshida and Smith (2008). Children were given novel and familiar objects to explore as they sat in a chair with no table so that each object could only be held by one or two hands. The child was given one object at a time to look at and explore for up to 20 s.

The data were coded using a custom-made software application that allowed a coder to compare an image taken from the camera to an image of a computer-rendered object. Here, we will report two analyses. The first is at a coarser grain, and just asked whether the view was “near planar” (within 15°) for each of the 6 possible planar views compared to a random object manipulation. The second analysis yields a detailed continuous presentation of the actual *x*, *y*, and *z* coordinates, a map of dwell times. The 18-month-old children showed no preference for the planar compared to baseline when they explored either the novel or the familiar objects. In contrast, the 24-month-old children showed marked preferences for the planar views for known but not for novel objects as shown in Figure 6.10. These results suggest an emerging preference for planar views in the active exploration of objects that begins with known object shapes and thus potentially may develop from experience with those particular objects. An important detail to consider here is that in the James et al. study, adults spent around 70% of their dwell time around planar views. This is considerably higher than the values here, even for the older group, so it seems that we have identified the beginning of this phenomenon.

**(p. 122 )**

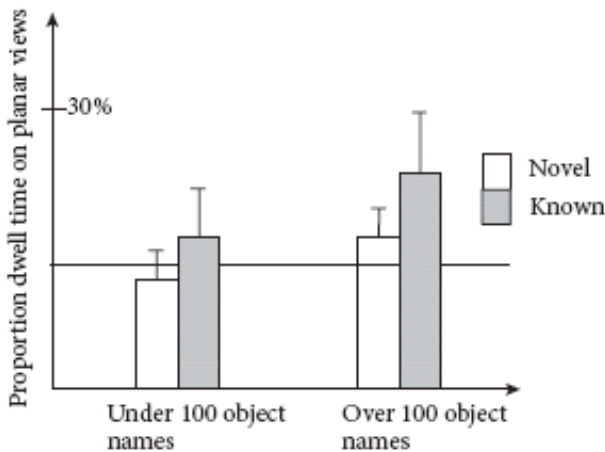


Figure 6.10 **Dwell times on planar views given exploration of novel and known objects for children with fewer and with more than 100 object names in productive vocabulary as compared to that expected (the solid line) by random object rotations (Pereira et al., 2007 ).**

To the best of our knowledge, there are no prior developmental studies directly comparing children’s recognition of objects from 3/4 and planar views and no prior studies of the views of objects that children actively generate for themselves as they explore objects. This is a critical gap in our understanding of the development of visual object recognition. Children’s first-hand views of objects are the visual experiences on which they must build their object recognition systems and their representations of specific objects (see chapter by Johnson in this volume). That these views change with development—that younger children present different views to themselves than do older children—suggest a link between perceptual development and action, with developmental changes in object representations perhaps driving changes in the views that children present themselves. These self-generated views, in turn, seem likely to be driving forces in the development of object representations. Although we have not made the direct link yet, the fact that these changes in preferred views begin at the same time when children learn many object category names, begin to build abstract and category encompassing representations of object structure, and engage in shape-based object substitutions in play suggest that they may be connected. At the very least, all the results reviewed thus far suggest that fundamentally important changes in visual object recognition—evident in a variety of task domains—are occurring between 18 and 24 months.

## Axes of Elongation

Planar and 3/4 views are defined by the relation of the object's axis of elongation to the viewer; that is, in the planar view, the axis of elongation is parallel or perpendicular to the viewer's line of sight. Many theorists of visual object recognition have posited that axes of elongation (and/or symmetry, which is often correlated with the axis of elongation) play a particularly critical role in a current input's activation of stored object representations (Biederman, 1987; Marr & Nishihara, 1992). This is because the object's major axes are proposed to play an important role in parsing objects into their main parts and for the comparison of sensory inputs to stored representations (Biederman, 1987; Jolicoeur, 1985, 1990; Marr & Nishihara, 1992; Ullman, 1996). This makes sense: the principal axes are enduring characteristics of objects and provide a systematic means for transforming and comparing images by defining a common reference frame for alignment. Axes of elongation and their relation to the body are also important determiners of how objects are picked up, held, viewed, and used (Goodale & Humphrey, 1998; Jeannerod, 1988, 1997; Jones & Lederman, 2006; Milner & Goodale, 1995; Turvey, Park, Dumais, & Carello, 1998).

Studies of the influence of axes of elongation in adult object recognition mainly involve the presentation of objects from various viewpoints that differ in the relation of the axes of elongation to the viewer. Put together, these studies have yielded mixed results. Studies that have used pictures of highly familiar objects rotated in the picture plane typically find, at best, small effects (Large, McMullen, & Hamm, 2003; Sekuler, 1996). As Large et al. note, strong top-down effects in adults' recognition of prototypical pictures of things may overwhelm any role for variations in the main axes. Consistent with this idea, Liu and Cooper (2001) found strong axis of symmetry effects in judgments about (p. 123) nonsense objects. Thus, the principal axes may be particularly important in setting up one's initial representations of an object, and perhaps in integrating multiple images into a coherent whole. In support of this idea, Jolicoeur (1985) found that axes of elongation were important in recognizing novel objects, but played a decreasing role with increasing object familiarity.

There is also evidence that object shape, and perceived axes of elongation and symmetry, depend on (and also influence) the perceived frame of reference (Quinlan & Humphrey, 1993; Rock, 1973; Sekuler, 1996; Sekuler & Swimmer, 2000). For example, the same pattern can be seen as a square or a diamond, depending on how one assigns the reference frame and the

main axis of symmetry (Rock, 1973). Particularly relevant to our interest in the relation between action and perception, the perceived axes of elongation and symmetry in adults are also influenced by motion (Bucher & Palmer, 1985; Rock 1973; Sekuler & Swimmer, 2000). Adults are biased to see both the main axis of symmetry and the main axis of elongation as parallel to the path of movement (Morikawa, 1999; Sekuler & Swimmer, 2000).

There is almost no evidence on how children perceive axes of elongation, on how principle axes relate to the development of object recognition or on how action—holding and moving objects—may be related to the perceptual definition of the principle axes of an object (but see E.J. Gibson, 1969; Turvey et al., 1998) even though object shape and axes of elongation strongly influence not only how we hold and grasp objects, but also how objects may be used functionally (Goodale & Humphrey, 1998; Jeannerod, 1988; Jones & Lederman, 2006; Milner & Goodale, 1995). However, if the axes of elongation are important for setting up frames of reference for the perception of shape, as many theories of visual object recognition suggest, and if axes of elongation determine how we hold, grasp, and use objects, then children’s actions on objects may play an important developmental role in their discovery and representation of these axes, and thus in visual object recognition. There are many well-documented demonstrations of how action organizes perceptual development in other domains (e.g. Amso & Johnson, 2006; Bushnell & Bourdreau, 1993; Gibson, 1969; Needham, Barrett, & Peterman, 2002; Ruff & Rothbart, 1996). Two recent developmental studies in our laboratory suggest that this may also be the case in children’s representation of the major axes of an object.

The first relevant study (Smith, 2005) demonstrates how action may promote the discovery of deeper regularities concerning three-dimensional object structure, particularly, the definition of an object’s axes of elongation and symmetry. The participants were 24- to 30-month-old children. In the first experiment, the children were given a three-dimensional object to hold in one hand that is shown in Figure 6.11A. This nearly sphere-like exemplar object did not have a single main axis of elongation. In one condition, children moved the object up and down along a 1-m vertical path. In a second condition, they moved the object back and forth on a 1-m horizontal path. Immediately following, children were asked to group the exemplar object with other like things. No movement was involved in this categorization task. Children who had acted on the exemplar by moving it vertically grouped it with objects elongated on their vertical axes (Figure 6.11B), but children who had moved the exemplar horizontally grouped it

with objects elongated on their horizontal axes. These categorization choices emerged only as a consequence of action and not when children merely observed someone else move the exemplar along the same path. The path of action thus selected or highlighted the corresponding visual axis, altering the perceived similarity of the exemplar to the test objects.

The second experiment in this study used an exemplar like that shown in figure, part C, an exemplar not quite symmetrical around its center axis. The actions are illustrated in the figure, part D. Children who held the exemplar in one hand by one part and moved it back and forth subsequently grouped the exemplar with test objects (part E) that were less symmetrical in shape than the exemplar itself, as if they saw the exemplar as composed of two unequal parts. Children who held the exemplar in the two **(p. 124 )**

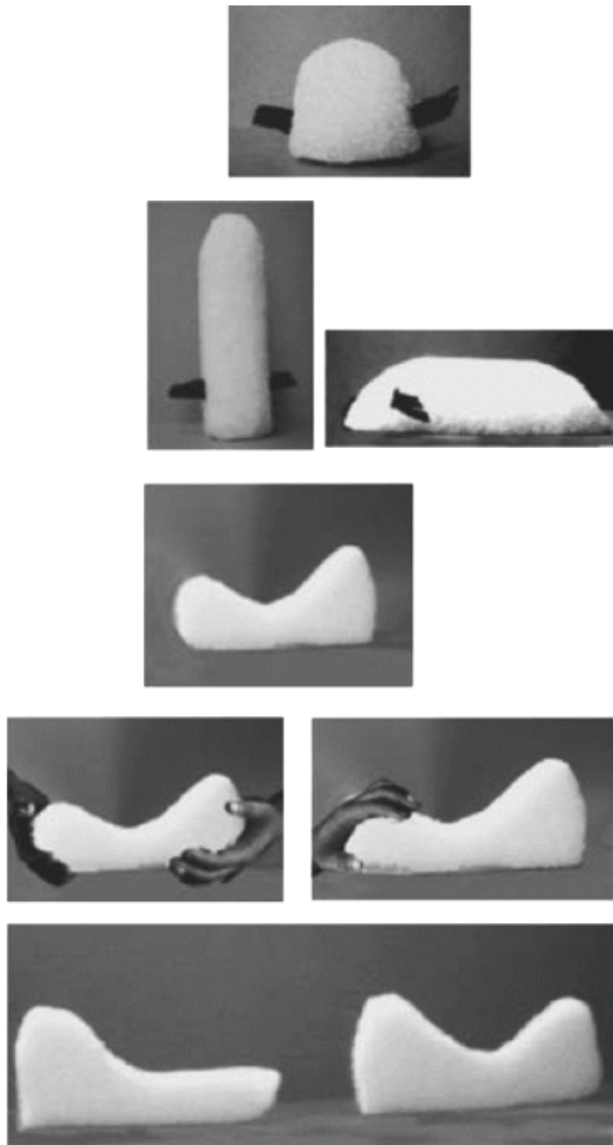


Figure 6.11 **Exemplars and test objects used in Smith ( 2005 ).**

hands and rotated it about a central axis subsequently grouped the exemplar with objects more symmetrical in shape than the exemplar, as if they saw the exemplar as composed of two comparable and symmetric parts. Again, these results only obtained when children acted on the objects, not when they watched someone else do the action. The enacted action appears to have selected compatible visual descriptions of object shape.

Axes of elongation and symmetry are higher-order dimensions of object shape fundamental to processes of human object recognition (e.g., Marr,



1982). These results suggest that they may be developmentally defined not by vision alone but by the in-task coordination of (p. 125) visual and motor processes. This is potentially of considerable importance. Theories of object recognition are for the most part theories of static object recognition (see also, Liu & Cooper, 2003). Yet how we act on objects is intimately related to their shapes, and may even developmentally be defining of them. Every time the child lays a doll in a doll bed, or perhaps on top of a block as a pretend bed, the child acts in ways that may help define the major axes of an object and the frame of reference for comparing one shape to another. There are physical and biological constraints on how we can hold and move objects of different shapes and thus highly constrained associations between symmetry, elongation, and paths of movement that may bootstrap these developments. Related to this idea is Morikawa's (1999) proposal that adults are biased to perceive movement parallel to an object's long axis and this bias derives from a regularity in the world, that objects in general move on paths parallel to their long axis (there are obvious exceptions: people, e.g., move orthogonally to their long axis). Still, a person's movements of objects (rather than, or as well as, how objects move on their own) may well be systematically related to shape in ways that matter to the development of object recognition. And critically, the visual information young learners receive about objects varies systematically with their own actions on those objects. Thus it seems likely that changes in visual object recognition support developmental changes in action (including object substitution in play) and that those activities in turn help define and refine structural descriptions of shape. This, then, is another potential loop of codeveloping processes, of causes as consequences and consequences as causes. At the very least, the present results show that action has a strong influence on the range of shapes 2-year-olds take as being similar and appears to do so by defining axes of elongation and symmetry.

Our most recent work on this topic (Street, Smith, James, & Jones, 2008) uses a task that is commonly used to diagnose developmental delays and is included in many assessment procedures. This is a shape-sorting task in which children are presented with objects of various shapes and asked to fit them into a container through holes specific to those shapes (Wyly, 1997). Although there are normative standards for preschool children's success in these tasks (and their perseveration in the task), there is remarkably little empirical study of the processes and skills that underlie success. We have preliminary evidence in a version of a shape-sorting task designed to measure children's ability to abstract the axis of elongation of shapes of various complexities.

Our approach is based on the “posting” studies of Efron (1969) with adults and neuropsychological patients (see also Goodale & Milner, 1992; Milner, Perrett, & Johnston., 1991; Warrington 1985). In these studies, subjects were given a range of “Efron rectangles”: flat, simple, plaques that differ in their height–width ratio. Their task was to insert them in a slot aligned at a particular orientation. The critical dependent measure was whether subjects oriented the handheld object to match the slot. We use a much simpler version of this “posting task” to ask whether—given the goal of inserting an object in a slot—children align that object’s axis of elongation to the axis of elongation of the slot. This task thus provides a good measure of children’s ability to abstract the axis of elongation and to make use of that information in action. The participants are 30 children in two age groups, 17–18 and 23–24 months of age. Children are presented with a box with a quite large slot (7 by 21 cm) oriented either horizontally or vertically. They are then given objects, one at a time, and asked to put them into the slot. All the objects can be easily fit into the slot—either by aligning the axis of orientation or by tilting the object so that the foreshortened end goes in first. The key independent variables were: the Orientation of the objects on the table (that were Matching or Mismatching the orientation of the slot); and the Complexity of the objects. Complexity of shape was manipulated in three ways: Shape Matches, solid rectangular blocks whose shape matched the slot; Simple Shapes, novel forms with height–width ratios comparable to the (p. 126 ) rectangular blocks); and Known Shapes, complex real objects with height–width ratios comparable to the rectangular blocks but with multiple parts and a canonical axis of orientation (e.g., a tiger versus a rocket). Children wear the head-camera in this study so that we can record the alignment of object and slot from their point of view.

This is a highly enjoyable and engaging task and on virtually every trial the children inserted the object into the slot in one way or another. The first main result, however, is that this skill undergoes considerable developmental change in this period. Eighteen-month-old children struggle in this task, often making many wrong attempts (see Figure 6.12). In contrast, 24-month-old children are nearly perfect, aligning and inserting the object rapidly and almost without error. Our main dependent measure is degree of alignment, measured from the head-camera view as shown in Figure 6.12. For the younger children, this angle averages 33° across all objects, that is, these children were typically off the mark, and their error was greater for complex than for simple objects. In contrast, older children’s alignment error was less 10° for all objects. How the objects were presented did not matter, perhaps because the children held and rotated them, exploring them, before

attempting insertion. These results again suggest marked growth during this developmental period in children's representation and use of the structural dimensions of three-dimensional shape.

## FROM VISUAL OBJECT RECOGNITION TO SYMBOLIC PLAY TO WORD LEARNING AND BACK

This chapter began with a phenomenon often known as symbolic play, an extremely interesting behavior that has been strongly linked to language learning, to social interactions in collaborative play, and to developing tool use (see Rakoczy, Tomasello, & Striano, 2006). The program of research reviewed in this chapter in no way explains symbolic play, since that explanation will likely consist of a cascade of interacting processes beyond those involved in perceiving and representing object shape. The findings reviewed here, however, do suggest that one component of that larger developmental story will be changes in fundamental processes of visual object recognition, which is the main focus of this chapter. The entire pattern of results reviewed here strongly suggests that there are significant and consequential changes

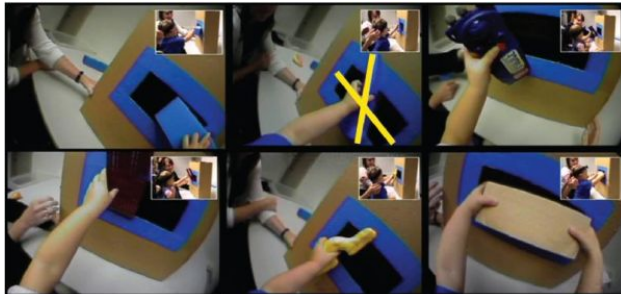


Figure 6.12 **Head-camera views from Street et al. ( 2008 ) of a 18-month-old infant inserting objects into slots. The smaller images show the view was an additional camera. As shown in the third image, alignment at first attempt is measured by the angle between the major axis of the slot and the major axis of the object to be inserted.**

(p. 127 ) in how children perceive, represent, and compare three-dimensional object shape, a shift from more piecemeal emphasis on local details to a sparse, and thus category encompassing, description of shape in terms of global geometric structure. These changes are seen in (1) the recognition of instances of common categories, (2) in object substitution in pretend

play, (3) in active exploration of objects, and (4) in actions that make use of structural properties.

From this first set of studies, we cannot know with any certainty what causes what, but it may well be, as suggested by the opening Figure 6.1, that there are causal influences in all directions. Development, after all, occurs in real time, in incremental steps, across a number of interleaved real-time experiences. The child hears a new object named (say an oddly shaped mug), uses it to drink from, sees and imitates his older brother pretend to use it as a hat. All these experiences influence what the child sees, what the child feels, and how this one experience is connected to other experiences. The inventiveness of human cognition, its adaptability and power, may, quite literally, be constructed from the overlapping, mutually influencing, interactions of many different tasks involving and educating the same component processes.

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